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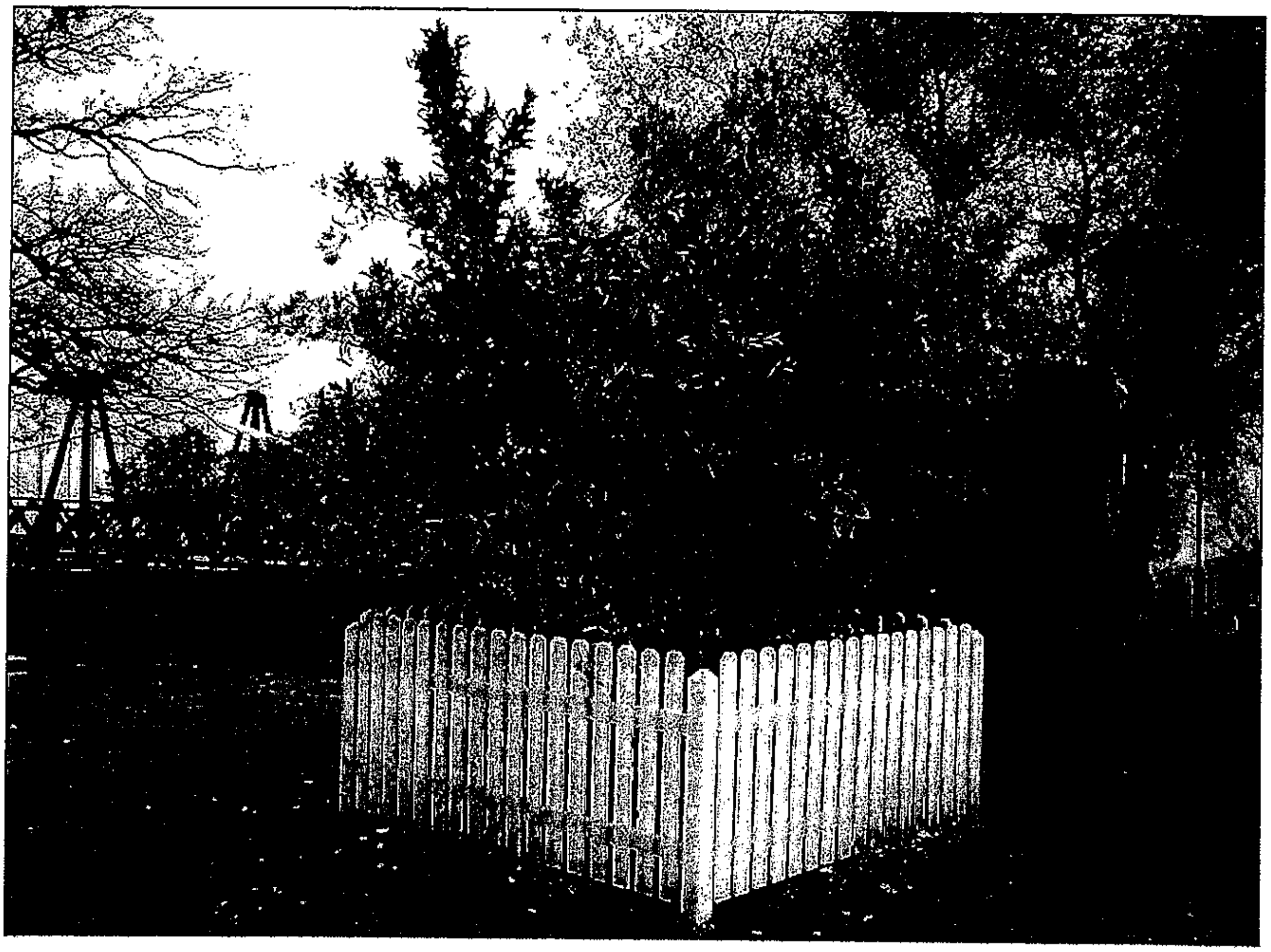
Chapter 12: Stoichiometry – Fun to Say, Fun to Do



It's nearly impossible to come up with a good image to start a chapter about stoichiometry, so I figured I'd just include this picture of what appears to be an imprisoned orange tree.

http://commons.wikimedia.org/wiki/File:The_Mother_Orange_Tree.jpg

Chapter 12: Stoichiometry – Fun to Say, Fun to Do

You're probably reading this chapter because you're being forced to do so by an authority figure of some kind. Or perhaps you're reading it for the pure love and wonder of science. Most likely, you're reading it because some teacher keeps saying "stoy – key – ah – meh – tree" and you have no idea what he or she is talking about.

Well, wonder no further. We're going to talk about the magical world of stoichiometry and how it can be used to enrich your life, etc.

Section 12.1: What the heck is Stoichiometry?

You probably don't have any clue what stoichiometry is, mainly because the word itself seems designed to make your brain melt right out of your ears. Fortunately, you have me, and I can give you this information in a way that's less likely to melt brains.

The word **stoichiometry** is just a fancy way of saying "the method you use to figure out how much of a chemical you can make, or how much you need, during a reaction." For example, if you're doing a reaction and want to make 88.5 grams of the product, you'd do a bunch of calculations to figure out how much of each reagent you'd need. Those calculations are stoichiometry.[1]

Irrelevant Information to Take Your Mind Off of Stoichiometry

Figure 12.1: The first person to use the word "stoichiometry" was Nicephorus I, the ecumenical Patriarch of Constantinople in the early 9th century. However, the term as he used it refers to the number of lines of text in the New Testament. This suggests that the term "stoichiometry" has been annoying people for over a millennium.

Image: Classical Numismatic Group, www.cngcoins.com

[1] They're actually referred to as "stoichiometric calculations", but since that doesn't exactly clear things up, I'll just call 'em stoichiometry.

As you've probably already discovered in your chemistry class, there are about a bazillion types of stoichiometric calculation out there. The good news, however, is that none of them are all that difficult. Seriously.

Section 12.2: Doing Stoichiometry

Before I show you some examples of stoichiometry, let me show you a handy picture that you'll be using a lot:[2]

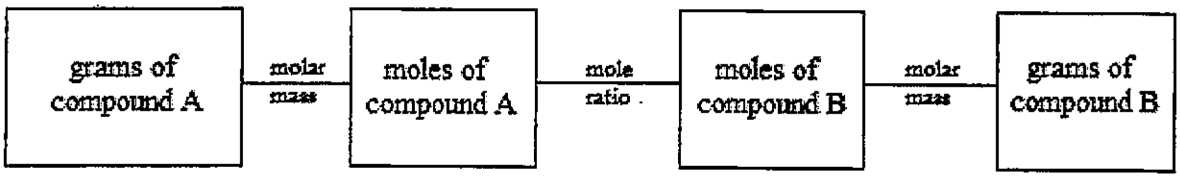


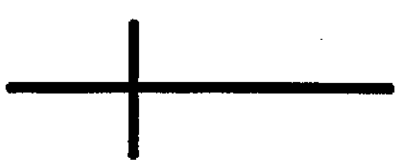
Figure 12.2: A handy picture that you'll be using a lot.

The best way to teach you how to use this picture to do stoichiometry is to simply give you a stoichiometry problem and solve it:

Problem: Given the equation $2 H_2 + O_2 \rightarrow 2 H_2O$, how many grams of water can be made with 50.0 grams of oxygen and an excess of hydrogen?[3]

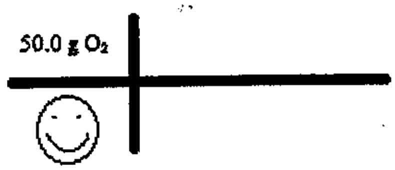
Answer: Let's go through the following steps to solve this problem:

1. **Determine what you're trying to figure out, and what you've been given:** In this problem, you've been given the value "50.0 grams of oxygen", so we'll call O_2 "compound A." The problem tells you that you're trying to find the "grams of water", so we'll call H_2O "compound B."[4]
2. **Figure out where you are on this table, and where you're trying to get:** Since we're given "50.0 grams of oxygen", we start in the "grams of compound A" box. Because we're trying to find out how many grams of water we'll be making, we end in the "grams of compound B" box.
3. **Make a "t":** You'll recognize the following steps from the mole calculation chapter (chapter 11).



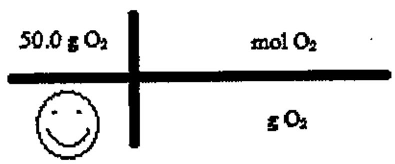
[2] That's my subtle way of saying "memorize this."
[3] When one of these problems refers to an "excess of [something]" what that really means is that there's so much of that compound hanging around that you really don't need to worry about it. Focus on the other reactant instead.
[4] It doesn't really matter which compound is A and which is B as long as you follow the steps in this guide.

4. **Put the thing that you were given in the problem in the top left of the t.** Since you were given the value "50.0 grams of oxygen" in the problem, put that in the top left of the t:[5]

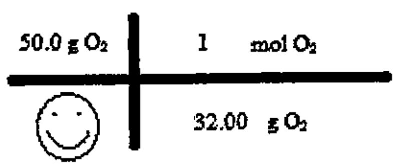


5. **Put the units of the thing that's in the top left in the space on the bottom right.** The units in the top left are "g O_2", so put "g O_2" in the bottom right:

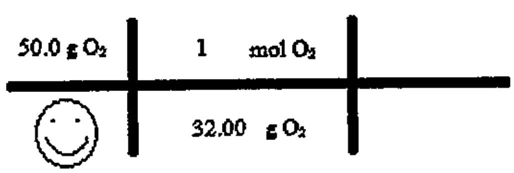
6. **Put the units of what you're trying to find in the top right.** Now, this one is a little more challenging. Obviously, we ultimately want to find the number of grams of water that can be formed. However, an examination of the table above tells us that we have to do several unit conversions to make that happen. As a result, our first conversion will simply be from grams of O_2 to moles of O_2:



7. **Put in the conversion factor between the things on the right.** The handy diagram says "molar mass", and molar mass is given to us in units of "grams in 1 mole", so we'll put a "1" in front of "mol O_2" and the molar mass of O_2 (32.00 g) in front of "g O_2":



8. Clearly, we're not done. In fact, all we've done is to do the same type of mole calculation that you learned about in Chapter 11. In order to get all the way to grams of H_2O, we'll have to do two more calculations. Let's extend the t-chart a little:



[5] The smiley face is put in the bottom left to make stoichiometry a happy and cheerful experience.

9. Move the units of the thing in the top left (mol O_2) to the bottom right. This is the same as step 5 above:

50.0 g O_2	1 mol O_2	
☺	32.00 g O_2	mol O_2

10. Put the units of what you're trying to find in the top right (same as step 6 above). Since we can't go directly to grams of water, we'll go to moles of water, as that's the next step on our handy chart:

50.0 g O_2	1 mol O_2	mol H_2O
☺	32.00 g O_2	mol O_2

11. Put in the conversion factors (same as step 7 above). In this step, the conversion factors are called the "mole ratio" because the conversion is from moles of one compound to moles of another compound. The conversion factors in the mole ratio step are the coefficients in front of each compound in the balanced equation:

50.0 g O_2	1 mol O_2	2 mol H_2O
☺	32.00 g O_2	1 mol O_2

12. Since we're not at grams of water yet, we need to go through the steps of extending the t-chart, writing the units from the top left in the bottom, and so forth (steps 4-7 again):

50.0 g O_2	1 mol O_2	2 mol H_2O	18.01 g H_2O
☺	32.00 g O_2	1 mol O_2	1 mol H_2O

13. In this, the last step, we multiply this stuff together like a series of fractions, where the stuff on the top is multiplied together and divided by the product of the stuff on the bottom multiplied together. This gives us an answer of 56.3 g H_2O.[6]

Made-up Fun Fact

Fractions were invented in 1875 by Patrick L. Fraction, a British accountant. Prior to that time, whenever somebody would cut a pie in two, they'd refer to each piece as "the product of a pie that hath been cleaved in twain." Because the many variations on that were annoying to say every time somebody took a piece of pie, Fraction came up with the convenient "fractions" that we use today.

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[6] The significant figures in this calculation are determined by the value "50.0 g O_2". Though it might seem that the numbers of moles would give us only one significant figure, they're exact values (i.e. there are approximately 18.01 grams of water in *exactly* one mole of water), so we treat them as if they have infinite significant figures.

Section 12.3: Limiting Reagents[7]

In the example above, we assumed that we had a limited amount of oxygen and an excess amount of hydrogen to work with. However, when we do reactions in the real world, we usually don't have an unlimited amount of one of the reagents – we usually have limited amounts of each.

What this means is that when we do a reaction with two reagents, one of them usually runs out before the other. The reagent that runs out is called the **limiting reagent** because it's the one that puts a limit on how much of the product will be formed.

You can think of this conceptually by using a recipe for bread that my old alcoholic grandfather came up with. To make this bread, he'd add two cans of beer to one bag of crushed up potato chips and bake the resulting mixture in the oven to make a mangled, disturbing "loaf" of "bread".[8] Given this disturbing recipe, how many loaves of his bread could he make with 24 cans of beer and 11 bags of chips?

To solve this problem, most people will do the following:

- Figure out how much bread you can make from 24 cans of beer. (12 loaves)
- Figure out how much bread you can make from 11 bags of chips. (11 loaves)
- The smallest answer is the correct one – 11 loaves. The limiting reagent (the thing that you ran out of) is chips, and the excess reagent (the thing that didn't run out) is the beer.

Figure 12.2: Delicious, delicious bread.

http://commons.wikimedia.org/wiki/File:Essene_flat_Bread_100_pct_Wheat_Sproud.JPG

Likewise, let's say that we're going to perform the reaction $2\ H_2 + O_2 \rightarrow 2\ H_2O$. If I have 14.0 grams of H_2 and 48.0 grams of O_2, how many grams of water can I make? To find this out, I:

- Find out how many grams of water you can make from 14.0 grams of H_2.[9] (126 grams)
- Find out how many grams of water you can make from 48.0 grams of O_2. (54.0 grams)
- The smallest answer is the correct one – 54.0 grams. The limiting reagent is oxygen and the excess reagent is hydrogen.

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[7] The term "limiting reactant" is also sometimes used.
[8] I wish I was kidding about this.
[9] These calculations are done using stoichiometry as discussed in Section 12.2.

Excess Reagents

In the beer/chips/bread example, I mentioned that we ran out of chips and had leftover beer. The reagent in a chemical process that isn't completely used up is called the **excess reagent**. Likewise, in the water example above, we said that hydrogen is the excess reagent because the oxygen ran out first.

To figure out how much of the excess reagent is left over, use the following equation:

$$\text{amount of excess reagent left over} = \text{original amount of excess reagent} - \text{original amount of excess reagent}\left(\frac{\text{amount of product that's actually formed}}{\text{amount of product that the excess reagent can make}}\right)$$

Or, to put it another way:

$$\text{amount of excess reagent left over} = \text{original amount of excess reagent} - \text{original amount of excess reagent}\left(\frac{\text{the small number from your stoichiometry calculations}}{\text{the big number from your stoichiometry calculations}}\right)$$

In the water example, we found that we could make 126 grams of water using 14.0 grams of H_2 and 54.0 grams of water using 48.0 grams of O_2. Because H_2 is the excess reagent, we can find that the amount that's left over is equal to:

$$\text{amount of excess } H_2 \text{ left over} = 14.0 \text{ grams} - 14.0 \text{ grams}\left(\frac{54.0 \text{ grams}}{126 \text{ grams}}\right)$$

$$= 8.0 \text{ grams } H_2$$

Water: Moist Friend of Mankind

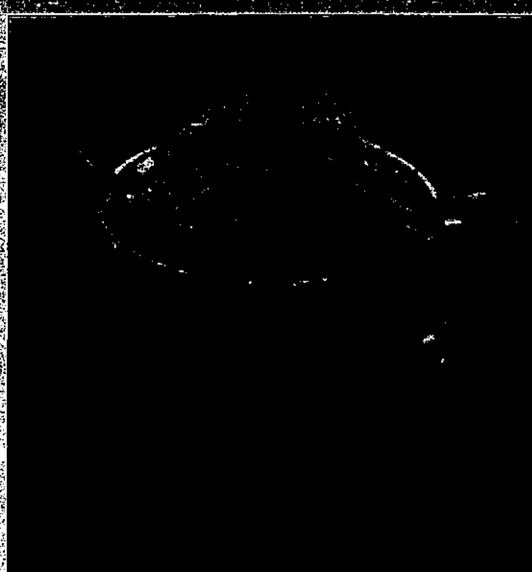


Figure 12.3: From the stupid drinks that hipsters pay $12 for (shown here) to the kiddie pools that the same hipsters fill in their living rooms to be "edgy", water has been both a friend and an enemy to mankind. I once saw on some TV show that the human body is mostly water. Well, it has a lot of water, anyway – something like 80%, but maybe less. I wasn't really listening because Angry Birds had just come out and I thought that was way more interesting than watching a show about water. Seriously, like I'm going to watch an hour-long show about water.

http://commons.wikimedia.org/wiki/File:Hot_chocolate_mug_with_whipped_cream.jpg

Section 12.4: Percent Yield

Let's say that, like everybody else in the world, you screw stuff up on a more-or-less continuous basis. This isn't to say that you're not a good person – it's just that you're human, and human beings screw up stuff all the time through either little or huge mistakes. If you're still under the impression that you're perfect, I've got bad news: Mom was lying to you when she said that you were her "perfect little angel."[10]

Given the presupposition that we all screw stuff up on a more-or-less continual basis, it stands to reason that we'll screw stuff up in the laboratory as well. One of the big questions we need to ask ourselves is "How did we manage to screw that up?" After all, if we know why we screwed something up we'll be less likely to screw it up in the future. The following types of error exist when performing chemical reactions:

- **Human error:** I put this first because it's the main cause of laboratory errors. Your friend Bobby might drop the crucible in the sink or you might accidentally think that you need 1.0 grams of a compound instead of 1.5 grams of a compound. The ways in which human beings can screw stuff up are varied and extremely creative. Human error can be partially accounted for by being extremely careful, but given that nobody is perfect, it will always exist to some extent or another.

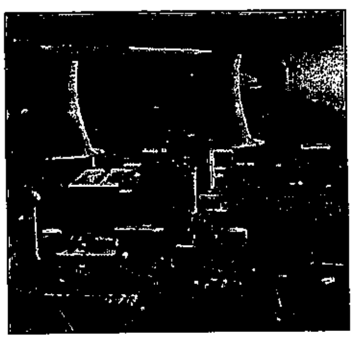


Figure 12.4: *The 1979 partial meltdown of the Three Mile Island nuclear power plant was due to human error. Apparently, the operators couldn't figure out that there was a stuck valve, and eventually radioactive water was released into the environment. Reactor 1 wasn't affected, so it's still chugging away, making power.*

http://commons.wikimedia.org/wiki/File:Three_Mile_Island_(color).jpg

- **Systematic error:** These are errors that are made in the same way every time due to quirks or limitations in the procedure. For example, if you were to have a faulty stopwatch, you'll always let your reactions run for 30 seconds more than they should. If your lab partner spits in your beaker every time you start a reaction, your product will always contain his spit. You get the idea. This type of error can usually be traced back to some error in the procedure – in other words, it's human error as manifested in the instructions you give yourself.

- **Instrumental/black box error:** You've got some machine and it gives you bad answers. These errors are called black box errors because the workings of the machines are mysterious and unknowable. For example, when you put a sample on a balance, the answer just shows up on a little computer screen. What happens inside of the balance? Who knows? It could be that the machine is humming along just fine, or it could be that the machine is full of rat poop and gives random answers. There's no fixing this type of error, though it can be minimized by calibrating

[10] More bad news: You're not actually an angel, either.

the machines ahead of time. Fortunately, this type of error is pretty uncommon with the stuff you'll see in a high school chemistry class, given the simplicity of most of the black boxes we use.

- **Unknown error:** You get done with the lab and you got a lousy answer. You were really careful with everything you did, so it wasn't human error. You made sure that your procedure was wonderful and that your equipment was all working properly. Well, here's the deal: Even though you think you did everything right, you still screwed up *somewhere*. Maybe Bobby still spits in the beaker and hasn't been telling you. Maybe the reagents were contaminated with pudding. Maybe somebody thought it would be funny to tape a penny to the bottom of your balance. All of this is my way of saying that sorry, bub – if you can't figure out what went wrong, it's probably a very well-hidden version of human error.

MISTAKING CAUSE FOR EFFECT.

Boy. "I say, Tommy, I'm blow'd if there isn't a Man a turning on the Cholera."

Figure 12.5: The man in this cartoon doesn't understand how his actions are causing him to spread cholera. For that matter, neither do I, because the cartoon is from 1849 and doesn't really make any sense. You know how old cartoons are: There are just a bunch of people hanging around and one of them is doing something and everybody else looks surprised for no reason. Weird.

http://commons.wikimedia.org/wiki/File:Mistaking_Cause_for_Effect_-_Turning_on_the_Cholera.jpg (public domain image)

Unfortunately, stoichiometric calculations assume that we're perfect in every way. If the calculation says that we'll make 75.0 grams of a compound, then we'll make 75.0 grams of a compound. What it doesn't take into account is the fact that there are inherent limitations to how well we can do things in the lab, and that these limitations result in smaller than expected quantities of product.

Fortunately, we have a way of figuring out how badly we screwed up: percent yield. The **percent yield** of a chemical reaction is a comparison of the amount of product you actually made, versus how much product that your stoichiometry calculations predicted you'd make. To find the percent yield of a reaction, use the following equation:

$$\text{percent yield} = \frac{\text{amount of product you actually made}}{\text{amount of product that stoichiometry predicted you'd make}} \times 100\%$$

What this means is that if your stoichiometry calculation predicted you'd make 75.0 grams of a compound and you actually made 58.0 grams of that compound in the lab, your percent yield would be:

$$\text{percent yield} = \frac{58.0\text{ grams}}{75.0\text{ grams}} \times 100\% = 77.3\%$$

Clearly, the better your percent yield, the fewer mistakes you made. For example, if you got a 10% yield, it means that 90% of your product is lost somewhere, never to be seen again. On the other hand, if you have a 90% yield, you've only lost 10% of your product, which is pretty good.[11] The only exception to this rule is if your answer is exactly 100.0% (which implies that you've made up your data because it's impossible to be perfect) or greater than 100% (which implies that you've either violated the law of conservation of mass or more likely that you have lots of impurities in your compound).

Awesome Errors in History

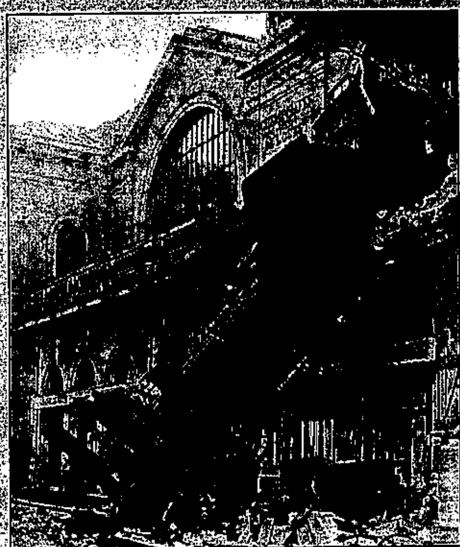


Figure 12.6: *This train ran off the end of the tracks at the Montparnasse rail station in 1895. Because the tracks were above ground, the train went out of the wall and onto the street below. The accident was caused by a defective brake. One person was killed: a woman who happened to be standing on the street below when the train crashed into her.*

Public domain image:
http://en.wikipedia.org/wiki/File:Train_wreck_at_Montparnasse_1895.jpg

[11] The actual relationship between percent yield and awesomeness is actually a lot more complicated than this. For example, some reactions don't ever reach completion, so it's *impossible* to get anywhere near 100% yield. Also, organic chemists frequently have multi-step reactions, where each step is likely to have about a 90% yield – those 90% terms really add up, making the final yield for the process very low even if each step was performed well. This is one of the reasons that many medications are so expensive – it takes a lot of chemical steps to make them, so you end up wasting a lot of stuff to get useful product.

12 Assessment

Lesson by Lesson

12.1 The Arithmetic of Equations

39. Interpret each chemical equation in terms of interacting particles.

a. $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$
b. $4NH_3(g) + 6NO(g) \longrightarrow 5N_2(g) + 6H_2O(g)$
c. $4K(s) + O_2(g) \longrightarrow 2K_2O(s)$

40. Interpret each equation in Problem 39 in terms of interacting numbers of moles of reactants and products.

41. Calculate and compare the mass of the reactants with the mass of the products for each equation in Problem 39. Show that each balanced equation obeys the law of conservation of mass.

42. Balance the following equation:

$$C_5H_{12}(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

Interpret the balanced equation in terms of relative number of moles, volumes of gas at STP, and masses of reactants and products.

12.2 Chemical Calculations

43. Explain the term *mole ratio* in your own words. When would you use this term?

44. What ratio is used to carry out each conversion?

a. mol CH_4 to g CH_4
b. L $CH_4(g)$ to mol $CH_4(g)$ (at STP)
c. molecules CH_4 to mol CH_4

★45. Carbon disulfide is an important industrial solvent. It is prepared by the reaction of coke with sulfur dioxide.

$$5C(s) + 2SO_2(g) \longrightarrow CS_2(l) + 4CO(g)$$

a. How many moles of CS_2 form when 2.7 mol C reacts?
b. How many moles of carbon are needed to react with 5.44 mol SO_2?
c. How many moles of carbon monoxide form at the same time that 0.246 mol CS_2 forms?
d. How many mol SO_2 are required to make 118 mol CS_2?

★46. Methanol (CH_3OH) is used in the production of many chemicals. Methanol is made by reacting carbon monoxide and hydrogen at high temperature and pressure.

$$CO(g) + 2H_2(g) \longrightarrow CH_3OH(g)$$

a. How many moles of each reactant are needed to produce 3.60×10^2 g CH_3OH?
b. Calculate the number of grams of each reactant needed to produce 4.00 mol CH_3OH.
c. How many grams of hydrogen are necessary to react with 2.85 mol CO?

47. The reaction of fluorine with ammonia produces dinitrogen tetrafluoride and hydrogen fluoride.

$$5F_2(g) + 2NH_3(g) \longrightarrow N_2F_4(g) + 6HF(g)$$

a. If you have 66.6 g NH_3, how many grams of F_2 are required for a complete reaction?
b. How many grams of NH_3 are required to produce 4.65 g HF?
c. How many grams of N_2F_4 can be produced from 225 g F_2?

48. What information about a chemical reaction is derived from the coefficients in a balanced equation?

49. Rust is produced when iron reacts with oxygen.

$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

How many grams of Fe_2O_3 are produced when 12.0 g of iron rusts?

★50. Lithium nitride reacts with water to form ammonia and aqueous lithium hydroxide.

$$Li_3N(s) + 3H_2O(l) \longrightarrow NH_3(g) + 3LiOH(aq)$$

a. What mass of water is needed to react with 32.9 g Li_3N?
b. When the above reaction takes place, how many molecules of NH_3 are produced?
c. Calculate the number of grams of Li_3N that must be added to an excess of water to produce 15.0 L NH_3 (at STP).

12.3 Limiting Reagent and Percent Yield

51. What is the significance of the limiting reagent in a reaction? What happens to the amount of any reagent that is present in an excess?

52. How would you identify a limiting reagent in a chemical reaction?

***53.** In a reaction chamber, 3.0 mol of aluminum is mixed with 5.3 mol Cl_2 and reacts. The following balanced chemical equation describes the reaction:

$$2Al(s) + 3Cl_2(g) \longrightarrow 2AlCl_3(s)$$

a. Identify the limiting reagent for the reaction.
b. Calculate the number of moles of product formed.
c. Calculate the number of moles of excess reagent remaining after the reaction.

***54.** Heating an ore of antimony (Sb_2S_3) in the presence of iron gives the element antimony and iron(II) sulfide.

$$Sb_2S_3(s) + 3Fe(s) \longrightarrow 2Sb(s) + 3FeS(s)$$

When 15.0 g Sb_2S_3 reacts with an excess of Fe, 9.84 g Sb is produced. What is the percent yield of this reaction?

55. Phosphoric acid reacts with sodium hydroxide according to the equation:

$$H_3PO_4(aq) + 3NaOH(aq) \longrightarrow Na_3PO_4(aq) + 3H_2O(l)$$

If 1.75 mol H_3PO_4 is made to react with 5.00 mol NaOH, identify the limiting reagent.

Understand Concepts

56. Calcium carbonate reacts with phosphoric acid to produce calcium phosphate, carbon dioxide, and water.

$$3CaCO_3(s) + 2H_3PO_4(aq) \longrightarrow Ca_3(PO_4)_2(aq) + 3CO_2(g) + 3H_2O(l)$$

a. How many grams of phosphoric acid react with excess calcium carbonate to produce 3.74 g $Ca_3(PO_4)_2$?
b. Calculate the number of grams of CO_2 formed when 0.773 g H_2O is produced.

***57.** Nitric acid and zinc react to form zinc nitrate, ammonium nitrate, and water.

$$4Zn(s) + 10HNO_3(aq) \longrightarrow 4Zn(NO_3)_2(aq) + NH_4NO_3(aq) + 3H_2O$$

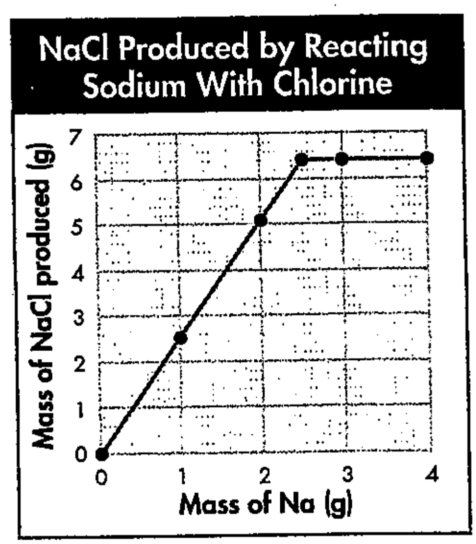
a. How many atoms of zinc react with 1.49 g HNO_3?
b. Calculate the number of grams of zinc that must react with an excess of HNO_3 to form 29.1 g NH_4NO_3.

58. If 75.0 g of silderite ore ($FeCO_3$) is heated with an excess of oxygen, 45.0 g of ferric oxide (Fe_2O_3) is produced.

$$4FeCO_3(s) + O_2(g) \longrightarrow 2Fe_2O_3(s) + 4CO_2(g)$$

What is the percent yield of this reaction?

59. In an experiment, varying masses of sodium metal are reacted with a fixed initial mass of chlorine gas. The following graph shows the amounts of sodium used and the amounts of sodium chloride formed.



a. Explain the general shape of the graph.
b. Estimate the amount of chlorine gas used in this experiment at the point where the curve becomes horizontal.

***60.** Hydrazine (N_2H_4) is used as rocket fuel. It reacts with oxygen to form nitrogen and water.

$$N_2H_4(l) + O_2(g) \longrightarrow N_2(g) + 2H_2O(g)$$

a. How many liters of N_2 (at STP) form when 1.0 kg N_2H_4 reacts with 1.2 kg O_2?
b. How many grams of the excess reagent remain after the reaction?

61. When 50.0 g of silicon dioxide is heated with an excess of carbon, 32.2 g of silicon carbide is produced.

$$SiO_2(s) + 3C(s) \longrightarrow SiC(s) + 2CO(g)$$

a. What is the percent yield of this reaction?
b. How many grams of CO gas are made?

62. If the reaction below proceeds with a 96.8% yield, how many kilograms of $CaSO_4$ are formed when 5.24 kg SO_2 reacts with an excess of $CaCO_3$ and O_2?

$$2CaCO_3(s) + 2SO_2(g) + O_2(g) \longrightarrow 2CaSO_4(s) + 2CO_2(g)$$

63. Ammonium nitrate will decompose explosively at high temperatures to form nitrogen, oxygen, and water vapor.

$$2NH_4NO_3(s) \longrightarrow 2N_2(g) + 4H_2O(g) + O_2(g)$$

What is the total number of liters of gas formed when 228 g NH_4NO_3 is decomposed? (Assume STP.)

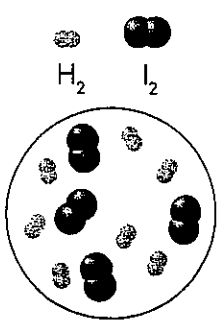
*64. Hydrogen gas can be made by reacting methane (CH_4) with high-temperature steam:

$$CH_4(g) + H_2O(g) \longrightarrow CO(g) + 3H_2(g)$$

How many hydrogen molecules are produced when 158 g of methane reacts with steam?

65. Suppose hydrogen gas and iodine vapor react to give gaseous hydrogen iodide.

a. Write the balanced equation for the reaction.
b. In the atomic window below, which reactant is the limiting reagent?
c. How many molecules of the reagent in excess remain at the completion of the reaction?
d. How many molecules of the limiting reagent need to be added to the atomic window so that all the reactants will react to form products?



66. The following reaction occurs when an automobile battery is charged.

$$PbSO_4(s) + H_2O(l) \longrightarrow PbO_2(s) + Pb(s) + H_2SO_4(aq)$$

a. Balance the equation.
b. How many grams of sulfuric acid are produced when 68.1 g of lead(II) sulfate react?

*67. Liquid sulfur difluoride reacts with fluorine gas to form gaseous sulfur hexafluoride.

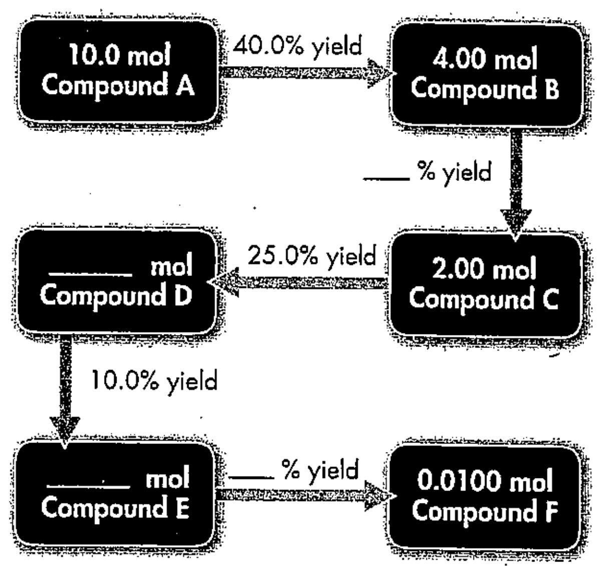
a. Write the balanced equation for the reaction.
b. How many fluorine molecules are required to react with 5.00 mg of sulfur difluoride?
c. What volume of fluorine gas at STP is required to react completely with 6.66 g of sulfur difluoride?

68. Ammonia (NH_3) reacts with oxygen (O_2) to produce nitrogen monoxide (NO) and water.

$$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(l)$$

How many liters of NO are produced when 1.40 L of oxygen reacts with ammonia?

*69. The manufacture of compound F requires five separate chemical reactions. The initial reactant, compound A, is converted to compound B, compound B is converted to compound C, and so on. The diagram below summarizes the steps in the manufacture of compound F, including the percent yield for each step. Provide the missing quantities or missing percent yields. Assume that the reactant and product in each step react in a one-to-one mole ratio.



Think Critically

70. Evaluate Given a certain quantity of reactant, you calculate that a particular reaction should produce 55 g of a product. When you perform the reaction, you find that you have produced 63 g of product. What is your percent yield? What could have caused a percent yield greater than 100 percent?

71. Explain Would the law of conservation of mass hold in a net ionic equation? Explain.

*__72. Calculate__ The element phosphorus is manufactured from a mixture of phosphate rock ($Ca_3(PO_4)_2$), sand (SiO_2), and coke (C) in an electric furnace. The chemistry is complex but is summarized by these two equations.

$$Ca_3(PO_4)_2 + SiO_2 \longrightarrow P_4O_{10} + CaSiO_3$$

$$P_4O_{10} + C \longrightarrow P_4 + CO$$

An excess of coke is reacted with 5.5×10^5 g of calcium phosphate and 2.3×10^5 g of sand.

a. Balance each of the equations.
b. What is the limiting reagent?
c. How many grams of phosphorus are produced?
d. How many grams of carbon are consumed?

73. Calculate Sulfuric acid reacts with calcium hydroxide to form calcium sulfate and water.

a. Write the balanced equation for the reaction.
b. Find the mass of unreacted starting material when 75.0 g sulfuric acid reacts with 55.0 g calcium hydroxide.

74. Apply Concepts A car gets 9.2 kilometers to a liter of gasoline. Assuming that gasoline is 100% octane (C_8H_{18}), which has a density of 0.69 g/cm^3, how many liters of air (21% oxygen by volume at STP) will be required to burn the gasoline for a 1250-km trip? Assume complete combustion.

*__75. Calculate__ Ethyl alcohol (C_2H_5OH) can be produced by the fermentation of glucose ($C_6H_{12}O_6$). If it takes 5.0 h to produce 8.0 kg of alcohol, how many days will it take to consume 1.0×10^3 kg of glucose? (An enzyme is used as a catalyst.)

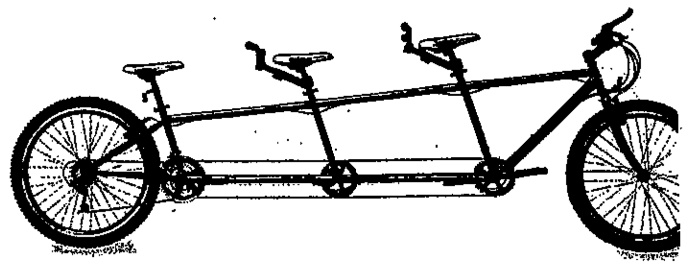
$$C_6H_{12}O_6 \xrightarrow{\text{enzyme}} 2C_2H_5OH + 2CO_2$$

76. Calculate A bicycle built for three has a frame, two wheels, six pedals, and three seats. The balanced equation for this bicycle is

$$F + 2W + 6P + 3S \longrightarrow FW_2P_6S_3$$

How many of each part are needed to make 29 bicycles built for three?

a. frames
b. wheels
c. pedals
d. seats



Enrichment

77. Calculate A 1004.0-g sample of $CaCO_3$ that is 95.0% pure gives 225 L CO_2 at STP when reacted with an excess of hydrochloric acid.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

What is the density (in g/L) of the CO_2?

*__78. Calculate__ The white limestone cliffs of Dover, England, contain a large percentage of calcium carbonate ($CaCO_3$). A sample of limestone with a mass of 84.4 g reacts with an excess of hydrochloric acid to form calcium chloride.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

The mass of calcium chloride formed is 81.8 g. What is the percentage of calcium carbonate in the limestone?

79. Calculate For the reaction below there are 100.0 g of each reactant available. Which reactant is the limiting reagent?

$$2MnO_2 + 4KOH + O_2 + Cl_2 \longrightarrow 2KMnO_4 + 2KCl + 2H_2O$$

80. Calculate The equation for one of the reactions in the process of reducing iron ore to the metal is

$$Fe_2O_3(s) + 3\,CO(g) \longrightarrow 2\,Fe(s) + 3\,CO_2(g)$$

a. What is the maximum mass of iron, in grams, that can be obtained from 454 g (1.00 lb) of iron(III) oxide?

b. What mass of CO is required to reduce the iron(III) oxide to iron metal?

81. Calculate Esters are a class of compounds that impart a characteristic odor to some fruits. The ester pentyl acetate, composed of carbon, hydrogen, and oxygen, has the odor of bananas. When 7.44 g of this compound undergoes complete combustion, 17.6 g CO_2 and 7.21 g H_2O are produced.

a. What is the empirical formula of pentyl acetate? (*Hint:* All the carbon ends up in the CO_2; all the hydrogen ends up in the H_2O.)

b. The molar mass of pentyl acetate is 130.0 g. What is the molecular formula of this compound?

c. Write the equation for the complete combustion of pentyl acetate.

d. Check your work by using your equation from part c to calculate the grams of CO_2 and H_2O produced by the complete combustion of 7.44 g of pentyl acetate.

*82. **Calculate** Nitric acid, HNO_3, is produced in a complex three-step process summarized by these unbalanced equations.

Step 1: $NH_3 + O_2 \longrightarrow NO + H_2O$

Step 2: $NO + O_2 \longrightarrow NO_2$

Step 3: $NO_2 + H_2O \longrightarrow HNO_3 + NO$

Notice that the nitric oxide, NO, produced in Step 3 is recycled into Step 2.

a. Balance each of the equations.

b. Assuming all the nitrogen from the ammonia will eventually be incorporated into the nitric acid, calculate the mass of nitric acid obtained from 88.0 g NH_3.

c. The concentrated nitric acid used in the lab is a 70.0% by mass solution of HNO_3 in water. Using your answer from part b, calculate the mass of ammonia needed to prepare 1.00 kg of concentrated nitric acid.

83. Calculate SO_3 can be produced in the following two-step process:

$$FeS_2 + O_2 \longrightarrow Fe_2O_3 + SO_2$$

$$SO_2 + O_2 \longrightarrow SO_3$$

Assuming that all the FeS_2 reacts, how many grams of SO_3 are produced when 20.0 g of the FeS_2 reacts with 16.0 g of O_2?

Write About Science

84. Explain Explain this statement: "Mass and atoms are conserved in every chemical reaction, but moles are not necessarily conserved."

85. Explain Review the "mole road map" at the end of Lesson 10.2. Explain how this road map ties into the summary of steps for stoichiometric problems shown in Figure 12.5.

CHEMYSTERY

Cookie Crumbles

Jack tried to make cookies that were extra sweet by adding more sugar than was in the recipe. What Jack didn't realize is that a recipe is like a balanced chemical equation. In order to get the desired product in the reaction of cooking, the reactants, or ingredients, must be combined in specific ratios. Jack changed the amount of sugar, but he didn't change any of the other ingredients. Therefore, he changed the ratios of the ingredients. Balanced chemical equations are important in cooking and in many other fields.

86. Infer If Jack's recipe calls for 2.5 cups of flour and 2 eggs, and Jack wants to scale up the recipe by 50 percent, then how much flour and eggs will he need?

87. Connect to the BIGIDEA How does Jack's baking experience illustrate the concept of a limiting reagent?

Cumulative Review

*88. How many electrons, protons, and neutrons are in an atom of each isotope?
   a. titanium-47
   b. tin-120
   c. oxygen-18
   d. magnesium-26

89. When comparing ultraviolet and visible electromagnetic radiation, which has
   a. a higher frequency?
   b. a higher energy?
   c. a shorter wavelength?

90. Identify the larger atom of each pair.
   a. sodium and chlorine
   b. arsenic and nitrogen
   c. fluorine and cesium

91. Write electron dot formulas for the following atoms:
   a. Cs
   b. Br
   c. Ca
   d. P

92. Which of these elements form ions with a 2+ charge?
   a. potassium
   b. sulfur
   c. barium
   d. magnesium

93. Distinguish among single, double, and triple covalent bonds.

94. Can a compound have both ionic and covalent bonds? Explain your answer.

95. How do you distinguish between a cation and an anion?

96. Name these ions.
   a. PO_4^{3-}
   b. Al^{3+}
   c. Se^{2-}
   d. NH_4^+

97. Name each substance.
   a. SiO_2
   b. K_2SO_4
   c. H_2CO_3
   d. MgS

98. Write the formula for each compound.
   a. aluminum carbonate
   b. nitrogen dioxide
   c. potassium sulfide
   d. manganese(II) chromate
   e. sodium bromide

*99. How many grams of beryllium are in 147 g of the mineral beryl ($Be_3Al_2Si_6O_{18}$)?

100. What is the mass, in grams, of a molecule of benzene (C_6H_6)?

*101. What is the molecular formula of oxalic acid, molar mass 90 g/mol? Its percent composition is 26.7% C, 2.2% H, and 71.1% O.

102. How many moles is each of the following?
   a. 47.8 g KNO_3
   b. 2.22 L SO_2 (at STP)
   c. 2.25×10^{22} molecules PCl_3

103. Write a balanced chemical equation for each reaction.
   a. When heated, lead(II) nitrate decomposes to form lead(II) oxide, nitrogen dioxide, and molecular oxygen.
   b. The complete combustion of isopropyl alcohol (C_3H_7OH) produces carbon dioxide and water vapor.
   c. When a mixture of aluminum and iron(II) oxide is heated, metallic iron and aluminum oxide are produced.

104. Balance each equation.
   a. $Ba(NO_3)_2(aq) + Na_2SO_4(aq) \longrightarrow BaSO_4(s) + NaNO_3(aq)$
   b. $AlCl_3(aq) + AgNO_3(aq) \longrightarrow AgCl(s) + Al(NO_3)_3(aq)$
   c. $H_2SO_4(aq) + Mg(OH)_2(aq) \longrightarrow MgSO_4(aq) + H_2O(l)$

105. Write a net ionic equation for each reaction in Problem 104.

106. Identify the spectator ions in each reaction in Problem 104.

107. Write a balanced chemical equation for the complete combustion of ribose, $C_5H_{10}O_5$.

If You Have Trouble With . . .

Question	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
See Chapter	4	5	6	7	7	8	8	9	9	9	9	10	10	10	10	11	11	11	11

Standardized Test Prep

Tips for Success

Anticipate the answer. Use what you know to predict what you think the answer should be. Then look to see if your answer, or one much like it, is given as an option.

Select the choice that best answers each question or completes each statement.

1. Nitric acid is formed by the reaction of nitrogen dioxide with water.

$$3NO_2(g) + H_2O(l) \longrightarrow NO(g) + 2HNO_3(aq)$$

How many moles of water are needed to react with 8.4 mol NO_2?

(A) 2.8 mol
(B) 3.0 mol
(C) 8.4 mol
(D) 25 mol

2. Phosphorus trifluoride is formed from its elements.

$$P_4(s) + 6F_2(g) \longrightarrow 4PF_3(g)$$

How many grams of fluorine are needed to react with 6.20 g of phosphorus?

(A) 2.85 g
(B) 5.70 g
(C) 11.4 g
(D) 37.2 g

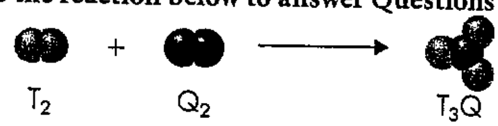
3. Magnesium nitride is formed in the reaction of magnesium metal with nitrogen gas.

$$3Mg(s) + N_2(g) \longrightarrow Mg_3N_2(s)$$

The reaction of 4.0 mol of nitrogen with 6.0 mol of magnesium produces

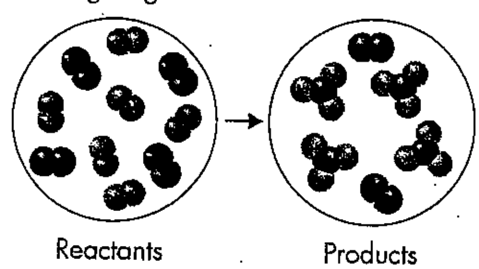
(A) 2.0 mol of Mg_3N_2 and no excess N_2.
(B) 2.0 mol of Mg_3N_2 and 2.0 mol of excess N_2.
(C) 4.0 mol of Mg_3N_2 and 1.0 mol of excess Mg.
(D) 6.0 mol of Mg_3N_2 and 3.0 mol of excess N_2.

Use the reaction below to answer Questions 4 and 5.



4. Write a balanced equation for the reaction between element T and element Q.

5. Based on the atomic windows below, identify the limiting reagent.



For each question, there are two statements. Decide whether each statement is true or false. Then decide whether Statement II is a correct explanation for Statement I.

	Statement I		Statement II
6.	Every stoichiometry calculation uses a balanced equation.	BECAUSE	Every chemical reaction obeys the law of conservation of mass.
7.	A percent yield is always greater than 0% and less than 100%.	BECAUSE	The actual yield in a reaction is never more than the theoretical yield.
8.	The amount of the limiting reagent left after a reaction is zero.	BECAUSE	The limiting reagent is completely used up in a reaction.
9.	The coefficients in a balanced equation represent the relative masses of the reactants and products.	BECAUSE	The mass of the reactants must equal the mass of the products in a chemical reaction.
10.	A mole ratio is always written with the larger number in the numerator.	BECAUSE	A mole ratio will always be greater than 1.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	12.2	12.2	12.3	12.1	12.3	12.1	12.3	12.3	12.1	12.2

c. Hydrochloric acid reacts with oxygen gas to form liquid water and chlorine gas.

d. Aqueous calcium hydroxide reacts with acetic acid to form water and aqueous calcium acetate.

e. Oxygen gas reacts with solid lead(II) sulfide to form sulfur dioxide gas and lead(II) oxide.

f. Solid lithium oxide reacts with water to form aqueous lithium hydroxide.

g. Solid manganese dioxide reacts with oxalic acid to form solid manganese(II) oxide, water, and gaseous carbon dioxide.

h. Gaseous diboron hexahydride reacts with oxygen gas to form liquid water and solid diboron trioxide.

103. Complete and then balance each of these equations.

a. $HCl(aq) \xrightarrow{\text{electricity}}$

b. $Br_2(l) + AlI_3(aq) \longrightarrow$

c. $Na(s) + S(s) \longrightarrow$

d. $Ba(OH)_2(aq) + HNO_3(aq) \longrightarrow$

e. $C_7H_{14}O_2(l) + O_2(g) \longrightarrow$

f. $Ni(NO_3)_2(aq) + Na_2CO_3(aq) \longrightarrow$

104. Balance each of these equations.

a. $MnO_2 + HCl \longrightarrow MnCl_2 + Cl_2 + H_2O$

b. $PCl_5 + H_2O \longrightarrow H_3PO_4 + HCl$

c. $Ca_3P_2 + H_2O \longrightarrow PH_3 + Ca(OH)_2$

d. $Li_3N + H_2O \longrightarrow LiOH + NH_3$

e. $H_2O_2 + N_2H_4 \longrightarrow N_2 + H_2O$

f. $SiCl_4 + Mg \longrightarrow MgCl_2 + Si$

g. $V_2O_5 + H_2 \longrightarrow V_2O_3 + H_2O$

h. $HBr + KHSO_3 \longrightarrow KBr + H_2O + SO_2$

105. Use Table 11.3 to predict whether a precipitate will form when aqueous solutions of these pairs of salts are mixed. If a precipitate forms, write its formula.

a. ammonium sulfate and barium bromide

b. chromium(II) chloride and lithium carbonate

c. potassium nitrate and sodium chloride

d. sodium sulfide and mercury(II) nitrate

106. Write a balanced complete ionic equation for each of these double-replacement reactions. All the reactants are in aqueous solution.

a. nickel(II) chloride + potassium phosphate

b. acetic acid + calcium hydroxide

c. calcium iodide + sodium sulfate

d. sodium hydroxide + lead(II) nitrate

107. Identify the spectator ions in each of the reactions in Problem 106.

108. Write net ionic equations for each of the reactions in Problem 106.

Chapter 12

109. Interpret each equation in terms of interacting particles.

a. $H_2 + F_2 \longrightarrow 2HF$

b. $2K_3PO_4 + 3CoCl_2 \longrightarrow Co_3(PO_4)_2 + 6KCl$

c. $2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2$

d. $Fe + S \longrightarrow FeS$

110. Write all possible mole ratios for these equations.

a. $2NO + Cl_2 \longrightarrow 2NOCl$

b. $2KClO_3 \longrightarrow 2KCl + 3O_2$

c. $3N_2H_4 \longrightarrow 4NH_3 + N_2$

d. $2Na + O_2 \longrightarrow Na_2O_2$

111. Show by calculation that the following equations obey the law of conservation of mass:

a. $3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$

b. $4HCl + O_2 \longrightarrow 2H_2O + 2Cl_2$

c. $2Li + S \longrightarrow Li_2S$

d. $2CH_4O + 3O_2 \longrightarrow 2CO_2 + 4H_2O$

112. Nitric acid, HNO_3, is produced by a process that allows nitrogen dioxide to react with water.

$$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$$

a. How many moles of nitrogen dioxide, NO_2, are required to produce 3.56 mol of nitric acid?

b. How many moles of water react with 0.946 mol of nitrogen dioxide?